Lecture (5)

Grids in Numerical Weather and Climate Models

5.1 Introduction

Numerical models are playing an increasing role in:

1. understanding and, 2. predicting weather and climate.

The models divide the area of interest into a set of grids and then make use of observations of variables such as surface pressure, winds, temperature and humidity at numerous locations throughout the globe. The observed values are then *assimilated* and used by the model to predict future evolution of the earth's weather and climate.

In the mid 20th century, models evolved from a simple model with a single atmospheric layer to a multi-layer primitive equation model capable of predicting cyclone development.

Due to the amount of computer processor time, memory, and disk storage required to run numerical models, the atmosphere cannot be represented perfectly by the *analytical model* and thereby is approximated by a *finite data set*. The atmosphere is represented in a model by a three dimensional set of points, called grids that cover the region of interest.

Figure 1 demonstrates the importance of the number of discrete grid points in order for the model to best represent the atmospheric structures. Figure 1a uses a grid spacing of 1 in. whereas Figure 1b uses a grid spacing of 0.5 in. Comparison of the two figures shows how increasing the number of grid points allows the model to better represent the actual wave function. As the number of discrete grid points increases, so increases the representation of the atmosphere. The NWP models in the 1950s had grid points every few hundred kilometers in the horizontal, whereas today, models used in operational forecasting have grid points every 10-100 km. The horizontal distance between the adjacent grids are often known as grid spacing or resolution.

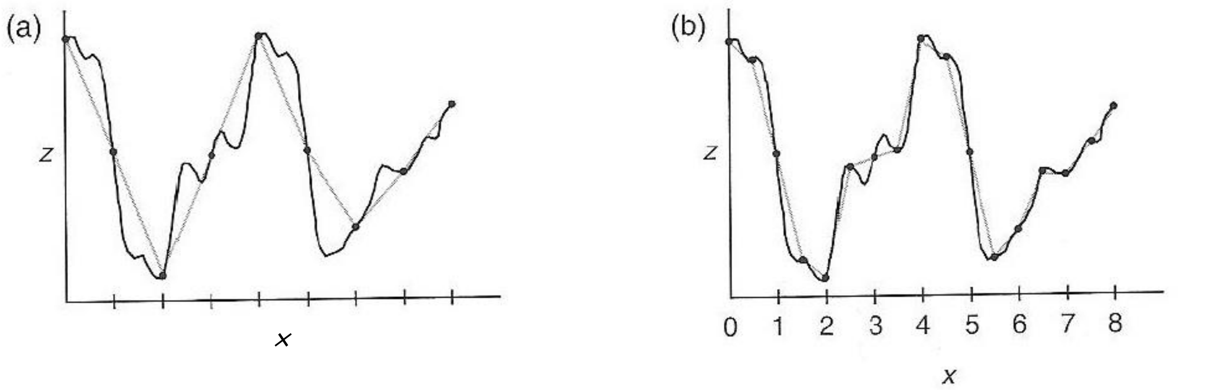
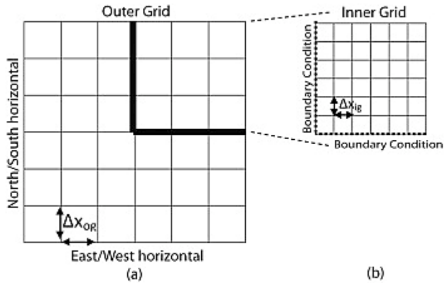


Figure 1. The effect of increasing the number of grid points

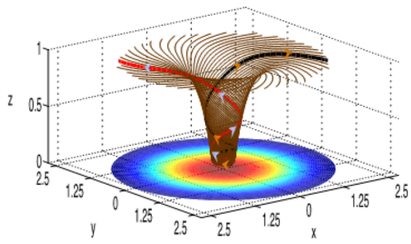
Many models have the ability to nest finer grids within a coarse grid resulting in a nested grid with much higher resolution.

Figure 2.



The vertical resolution of numerical models improved alongside horizontal resolution, such that models today can have more than 50 vertical layers.

Figure 3.



The resolution of a model also depends on the area coverage. General circulation models (GCMs), which are **global**, typically have coarse resolutions and are necessary for long range forecasts. **Regional** models often called limited area models, have finer resolution and are used for short-range forecasts. With the increase in computer power, high resolution regional models are covering larger area, whereas, global models are having finer resolutions.

The numerical schemes are designed to convert the set of partial differential equations into a set of algebraic expressions. The process involves representation of the solution by a finite data set.

This can be achieved using two different methods:

1. **Series expansion method:** This method represents a finite set of continuous expansion functions. According to the type of function, it may be classified as a spectral method or a finite element method.
2. **Grid-point method:** In this method, the equations are approximated on grid points using a finite set of data. Finite difference is an example of the grid-point method.

Series expansion and grid-point methods are used extensively for spatial derivatives. However, the time derivative is almost always approximated using the finite difference method. Most short-range and regional models are grid-point models.

5.2 A brief history of model grids

Richardson proposed to divide the earth's surface into a grid, with each grid cell the base of a vertical column of the atmosphere. Each vertical column was then divided into several layers, resulting in a three-dimensional grid of atmospheric boxes.

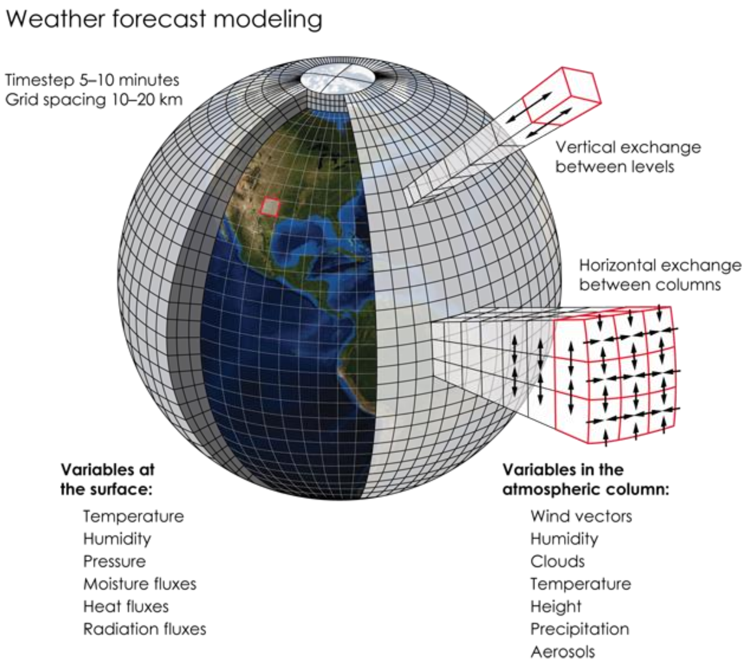


Figure 4.

5.3 Shapes of grids

There are different grid shapes used in numerical models; e.g., rectangular, triangular, and hexagonal (Figure 5). There are various advantages and disadvantages of these grids in relation with: (i) Suitability for scales; (ii) Efficiency on different computer architectures; (iii) Conservation of mass and other quantities؛ and (iv) Capability of local grid refinement and regional domains.

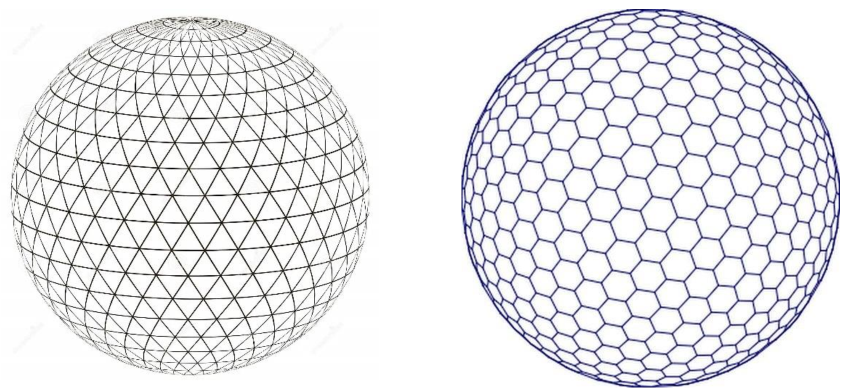


Figure 5. Examples of rectangular or latitude-longitude grid, triangular grid and hexagonal grid.

5.3.1 Rectangular/square grids

The rectangular/square (or latitude-longitude) grid is the most commonly used grid in the NWP models. It is simple but suffers from “the polar problem” where the lines of equal longitude, converge to points at the poles. The poles are unique points and may cause violation of global conservation laws within the model.

5.3.2 Triangular grids

Triangular grids are not used as often in models as are rectangular grids. It gives almost homogeneous and quasi-isotropic coverage of the sphere. The poles are chosen as two pentagonal points where the five rhombuses meet. The main advantage of the geodesic grid is that all the grid cells are nearly the same size.

5.3.3 Hexagonal grids

Similar to triangular grids, hexagonal grids are also not used as often as the rectangular/square grids. In this method, variables are calculated at each grid intersection between different hexagons, in addition to being calculated in the center of the hexagonal grid. It is able to accurately depict the polar regions since there was no need of stretching the grid in that region. The other advantages of the hexagonal grid are: (i) Removes the polar problem. (ii) Permits larger explicit time steps. (iii) Most isotropic compared to other grid types. (iv) Conservation of quantities in finite volume formulation. (v) Can be generalized easily to arbitrary grid structures.

5.4 Homework

1. Plot a suitable graph summarizes the above lecture.
2. Why we divide the area of interest into a set of grids?
3. Which is better: single atmospheric layer model or multi-layer primitive equation model? Why?
4. Why do we approximate the atmosphere by a three dimensional finite data set?
5. What is the difference between operational forecasting and research forecasting?
6. Why do we need previous weather forecast in the case of limited area prediction?
7. Why the PDE’s are converted into a set of algebraic expressions?
8. Why do we sometimes need a finer grid mesh?
9. Use google to find the difference between Series expansion method and Grid point method.